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Incidental catch, discards and potential post-release survival of fish captured in fixed-gear groundfish fisheries in NAFO 4T (Estuary and southern Gulf of St. Lawrence)

Les prises accidentelles, rejets et potentiel de survie suite à la remise à l'eau des poissons capturés dans les pêcheries de poissons de fond aux engins fixes dans l'OPANO 4T (Estuaire et sud du Golfe du Saint Laurent)

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ABSTRACT

In this document we provide information on the trends in fishing effort and estimates of incidental catch composition and discards in the principal fixed-gear (gillnets, longlines and handlines) groundfish fisheries of Northwest Atlantic Fisheries Organization (NAFO) division 4T, the Estuary and southern Gulf of St. Lawrence (1991-2008). We also present preliminary results of a study of potential post-release survival of discarded fishes that were captured by the fixed gear in question. The rates of incidental catch and discarding, as well as estimated total amounts, were by far the lowest in the cod handline fishery. Based on observations of post-release survival indicators for Atlantic cod (*Gadus morhua*), fish captured in this fishery are also generally in good condition and therefore survival of any discarded fish is expected to be good, particularly for more resilient taxa such as sculpins (Cottidae). At the other end of the scale for the fisheries considered here, rates of incidental catch and discarding were highest in the American plaice (*Hippoglossoides platessoides*) gillnet and in the Atlantic halibut (*Hippoglossus hippoglossus*) longline fisheries. However, total amounts of incidental and discarded catch were comparatively low in these fisheries because catches of the target species have generally been low (a situation that is changing for the Atlantic halibut fishery). Total discards were consistently the highest across years in the Greenland halibut (*Reinhardtius hippoglossoides*) gillnet fishery. Post-release survival of the most frequently discarded taxa in this fishery - skates, black dogfish and crabs – has not been evaluated.

RÉSUMÉ

Le présent document procure de l'information sur les tendances de l'effort de la pêche et les estimations de la composition des prises accidentelles et des rejets à la mer par la pêche aux principaux engins fixes (filets maillants, palangres et lignes à main) du poisson de fond dans la division 4T de l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO), couvrant l'estuaire et la partie sud du golfe du Saint-Laurent (1991-2008). On y présente également les résultats préliminaires d'une étude sur la survie éventuelle des poissons remis à l'eau à la suite de leur capture par les engins fixes susmentionnés. La pêche à la ligne à main à la morue a obtenu, et de loin, les plus bas taux de prises accidentelles et de rejets à la mer, ainsi que les plus basses estimations des quantités totales de prises accidentelles et de poissons rejetés. Selon les observations des indicateurs de survie après le rejet à la mer des morues (*Gadus morhua*), les poissons capturés lors de ces pêches sont généralement en bon état et, par conséquent, le taux de survie de tout poisson rejeté à la mer est estimé être bon, particulièrement pour les taxons plus résilients, notamment les chabots (Cottidae). À l'opposé, la pêche au filet maillant de la plie canadienne (*Hippoglossoides platessoides*) et la pêche à la palangre du flétan de l'Atlantique (*Hippoglossus hippoglossus*) ont obtenu les taux les plus élevés de prises accidentelles et de rejets à la mer. Cependant, la quantité totale de prises accidentelles et de rejets à la mer était comparativement basse dans ces pêches parce que les prises des espèces ciblées ont été généralement faibles (une situation qui change pour la pêche au flétan de l'Atlantique). Au fil des ans, la pêche au filet maillant du flétan du Groenland (*Reinhardtius hippoglossoides*) obtient constamment le total le plus élevé de rejets à la mer. Les taux de survie des taxons les plus souvent rejetés à la mer lors de cette pêcherie, soit la raie, l'aiguillat noir et le crabe, n'ont pas été évalués.

INTRODUCTION

Fisheries and Oceans Canada (DFO) convened a science advisory process workshop in Ottawa on January 11-14, 2010, to assemble available information on the uses of longlines, gillnets, and miscellaneous fishing gears (e.g. traps, pots, weirs, etc.) in Canadian waters, to examine the impacts of these gears on biodiversity and marine habitats, and to provide scientifically-based recommendations regarding potential avoidance or mitigation of these impacts where required and feasible. In this report which we presented at that meeting, we provide information on the trends in fishing effort and estimates of incidental catch composition and discards in the principal fixed-gear groundfish fisheries of Northwest Atlantic Fisheries Organization (NAFO) division 4T, the Estuary and southern Gulf of St. Lawrence. We also present preliminary results of a study of potential post-release survival of discarded fishes.

METHODS

INCIDENTAL CATCH AND DISCARD COMPOSITION

Directed observation is likely the only reliable manner of collecting information on the amount and species composition of fishery discards. Self-reported data such as those contained in harvester logbooks are typically not a suitable replacement for data collected directly by government or third-party at-sea observers (e.g., Walsh et al. 2002; H. Benoît, unpublished analyses). It is a condition of fishing license in all Gulf of St. Lawrence commercial groundfish fisheries to carry an observer, should one be assigned to a given fishing trip. Target coverage levels (i.e., percentage of trips covered by observers) can differ between fisheries, geographic areas and years. Target levels are typically 5% or 10% (though up to 25%) coverage in Gulf fixed-gear groundfish fisheries, though actual coverage varies (Benoît and Allard 2009). Coverage in DFO's southern Gulf Sentinel surveys is complete (100%). For more details on the observer program see Kulka and Waldron (1983) and Benoît and Allard (2009).

The main analyses presented in this working paper were undertaken separately for the different NAFO 4T fixed-gear groundfish fisheries, defined here based on target species and the gear employed: Atlantic cod, *Gadus morhua* (gillnet, longline, handline); Greenland halibut, *Reinhardtius hippoglossoides* (gillnet); winter flounder, *Pseudopleuronectes americanus* (gillnet); Atlantic halibut, *Hippoglossus hippoglossus* (longline); and, American plaice, *Hippoglossoides platessoides* (gillnet). The directed fishery for white hake (*Urophycis tenuis*) is not included because it has been closed since 1995 and there were relatively few observer records for that fishery in prior years. The data required for the present analyses (described in section 2.1.1) include fishery landings, fishing effort (summarized here as number of trips) and catch/discard composition data collected by observers.

Fishery-specific landings and trip data were extracted from DFO's ZIFF (zonal interchange file format) database. Records related to the targeted species were selected based on the 'main species sought' indicated by the harvester. If the 'main species sought' was not indicated for a particular record, the species that was most abundant in the catch was assumed to be the target species. Reported fixed-gear landings and trips directed at 'unidentified flatfish' during the period from 1991-1994 were attributed to American plaice and winter flounder in proportion to their respective reported landings, as these two were the most likely species caught in the areas fished.

Data on incidental (i.e., non-target) catches and discards (estimated kg) were extracted from the Gulf of St. Lawrence observer database. Observer records were attributed to the different fisheries based on the gear used and the database's 'main species' variable. Some incorrect attribution of both landings and observer records to particular fisheries likely occurred in cases where the reported or inferred main species was not the actual target, though this appears to be infrequent (<10% of records) and presumably largely inconsequential for the present workshop focussed on gear-specific rather than target-species-specific impacts.

INCIDENTAL CATCH AND DISCARD ESTIMATION

Estimating relevant fishery-scale incidental catch composition and discards from data collected during observer surveys with incomplete coverage requires inferring these catch variables for all fishing activities from those measured during observed activities (e.g., Liggins et al. 1997; Rochet and Trenkel 2005). Such inferences assume that observed activities directly or conditionally (given some sort of adequate model) approximate a random sample of all activities. For this assumption to be met, observers must be deployed to fishing activities in an unbiased manner. Furthermore, once an observer is deployed, their presence must not influence the fishing procedures (e.g., set duration, fishing locations, etc). Benoît and Allard (2009) have recently demonstrated that neither of these conditions are met in Gulf of St. Lawrence groundfish and shrimp fisheries. Certain vessels receive a disproportionate amount of observer coverage, while others receive little, if any (a deployment effect). Furthermore, the median observed fixed-gear groundfish trip in their analysis landed 15% less of their target species compared to landings from unobserved trips, suggesting changes in typical harvester fishing practices or fishing grounds when an observer is present (an observer effect). The authors also found that non-target commercial species (typically subject to discard bans) were more likely to be landed when an observer was present. Jointly, deployment and observer effects mean that fishery-wide inferences drawn from observer-collected data will likely be biased and their uncertainty under-estimated (Cotter and Pilling 2007; Benoît and Allard 2009). The degree to which deployment and observer effects impact the accuracy and precision of estimated quantities is unknown and there are therefore no corrections available to remedy the situation post-hoc; the catch and discard estimates provided in this working paper must therefore be interpreted cautiously. Furthermore, in light of the situation, we did not see the pertinence of estimating the precision around the point estimates.

Fishery-level catches or discards, $\hat{D}$ (in kg) of a given taxon *i* in fishery *f* and year *y* were estimated as:

1) $\hat{D}_{ify} = \bar{d}_{ify} \cdot C_{fy}$

where $\bar{d}_{ify}$ is the observed average catch or discard rate (in kg of taxon *i* per kg of target species catch) and C_{fy} is the total directed landed catch of the target species. C_{fy} excludes non-directed landings of the commercial species in fisheries targeting other species. Calculating the estimator $\hat{D}$ as in eqn. 1 assumes that target species and incidental catches in fishery *f* are correlated, as is indeed the case (r= 0.61, across fisheries and years). Observer records from the Sentinel fixed-gear surveys were included in the analysis to increase the amount of data used to estimate $\bar{d}_{ify}$. Data from the Sentinel surveys are pertinent to the present analysis as this fishery takes places on traditional fishing grounds, generally during traditional fishing seasons, and using commercial fishing gear. Furthermore, during a number of years of

commercial fishery moratoria, the Sentinel surveys were a (the) predominant groundfish fishery in the area. Catch and discard estimates were made for each year over the period from 1991-2008.

Catches and discards were estimated for a number of species or taxonomic groups. Because catches of marine mammals and sea turtles are inconsistently recorded in the observer database (e.g., often only in comments), we restrict our analysis to catches/discards of fish and invertebrates. Species were grouped, either because their individual numbers were small or because observers did not consistently (or accurately, in some cases) distinguish individual species, as appears to be the case for skates (Rajidae; e.g., Benoît 2006), sculpins (Cottidae) and eelpouts (Zoarcidae) (H. Benoît, unpublished results). We further distinguish species that are incidentally captured in one fishery but targeted in another. Because these species are under quota management, incidental catches that are landed are counted against the annual quota and the fishing mortality is therefore normally accounted for in their management plans.

POTENTIAL POST-RELEASE SURVIVAL

A study of the potential post-release survival of discarded fish was undertaken during the 2005 and 2006 fishing seasons. The objectives of the study were to evaluate the factors that affect post-release survival of discarded fish, to provide rough estimates of unaccounted fishing mortality, and eventually to evaluate the potential use of mandatory or voluntary release as a tool to minimise impacts of commercial fisheries on certain non-target species. The study comprised two parts, one based on data collected by observers and a second based on experiments. These are described in turn below.

Observer-collected data

During the 2005 and 2006 commercial groundfish fisheries and Sentinel survey, at-sea observers collected data on the condition of fishes captured. Specifically, observers measured the length of individual fish and scored their 'vitality' on a four level ordinal scale (Table 1). This type of scoring has been used in a number of discard survival studies and when it has been combined with tagging and release (e.g., Hueter and Manire 1994; Richards et al. 1995; Kaimmer and Trumble 1998) or aquarium holding of fish (present paper), ordinal scores have been found to correspond well with eventual relative survival.

Sampling was undertaken during most observed commercial and Sentinel survey fishing trips from all 2005 and 2006 NAFO 4T groundfish fisheries, except the Greenland halibut gillnet fishery. Up to 25 individuals of a given species were sampled by the observer during a given fishing set, at about the time when discarding would normally take place. Data were collected for a variety of commercial and non-commercial species, including species that are not presently discarded. In 2006, observers also noted the degree to which fish were injured on a 3-level ordinal scale (Table 2), in the hope that we might further our understanding of the factors that lead to mortality of discarded fishes. Aside from fish length, vitality and injury, observers also noted the amount of time the fish spent on deck prior to being sampled and reported other relevant factors such as the depth fished and set duration. The goal for collecting those data is to obtain the necessary information to analyze the factors that contribute to post-capture vitality. Unfortunately, those analyses could not be completed in time for the workshop and are not included in this paper.

It is important to note that this sampling was undertaken under the knowledge and cooperation of the harvesters. Given that harvesters were aware of the study's objectives it is possible that

enhanced caution was used when handling the fish, even though harvesters were asked to follow their normal fishing and fish handling procedures. Consequently, the vitality and injury scores reported by observers may provide a more optimistic picture (i.e. lower scores in Tables 1 and 2) compared to the condition of fish captured in unobserved fishing activities.

Post-capture survival experiments

Experiments were undertaken in 2005 and 2006 aboard the *CCGC Opilio* to relate 'pre-release' vitality codes (Table 1) to short term survival in a number of fish taxa. Fish were captured using a bottom trawl (286 Rock-hopper) rigged for commercial fishing and following common commercial fishing tow speed (2.75 knots) and set duration (1-2 hr.). When fish were brought aboard the vessel, they were handled as they would be on a commercial fishing vessel and sampled in the same manner as the observers would during the commercial fishery (see section *Observer collected data*): measured for length, vitality assessed and deck time noted. Fish were then individually tagged and placed in onboard refrigerated holding tanks (each 310 gallons) containing continuously exchanged sea water. Tank temperatures were set to the bottom temperatures where the fish were captured. Fish were held for at least 48 hrs (though often >72 hrs) to assess short term survival. Fish surviving the entire holding period were released alive.

Logistical constraints prevented us from carrying out similar experiments for fish captured by fixed gear. However, we believe that for a given taxon and vitality code level, short-term survival established in the experiments using a bottom-trawl should be generally applicable to fish caught by fixed gear. In our opinion, the biggest differences in potential post-release survival among fisheries for a given taxon should be reflected in the frequency with which fish are scored in the different vitality categories, rather than the conditional relationship between vitality code and survival.

Analysis of the post-capture survival-potential data

We present two aspects of our potential post-release survival studies in the working paper. First, we simply summarize the frequency of different vitality and injury scores noted by at-sea observers for a variety of species and for the different fishing gears. At present we have made no attempts to weight these data to derive fishery-level estimates of frequencies. Second, we summarize the results of our experimental study as the percentage of fish of each species in each vitality category that survived at least 48 hrs. post-capture. A more rigorous 'hazards' analysis of the survival experiment data is underway but could not be completed in time for the workshop.

RESULTS

FISHING EFFORT

Cod has traditionally been the focus of most groundfish fishing in NAFO 4T. Consequently, fishing effort decreased substantially following the first moratorium on cod fishing that was put in place in 1993, and has generally followed allowable cod fishing mortality since then (Fig. 1). Over 12,000 fixed-gear fishing trips were undertaken annually in the early 1990s. In more recent years, closer to 1,500 annual trips have been undertaken, with an increasing proportion of these directed at Atlantic and Greenland halibut. Fixed-gear generally comprised a higher proportion of the total groundfish-directed fishing effort in the area following the 1993 moratorium compared to the prior period.

CATCH AND DISCARD ESTIMATES

Cod (gillnets)

There was very little coverage of this and other NAFO 4T cod fisheries up to the time they were closed after the 1993 season (Fig. 2a). The Sentinel surveys were the only cod directed fishery in 1995-1997 (apparent observer coverage levels <100% likely reflect an incorrect attribution of fisheries). An index fishery was opened in 1998, followed by a reopening of the commercial fishery in 1999. All cod-directed fisheries in NAFO 4T were closed in 2003. Coverage levels since 1999 have been about 10% (Fig. 2a).

During the early 1990s, other commercial species (mainly white hake, *Urophycis tenuis*) comprised a high proportion of total catches in the cod gillnet fishery (Fig. 2b). This proportion was lower in the late 1990s when the fishery was reopened and spiny dogfish (*Squalus acanthias*) was the principal incidentally captured commercial species. Over the series, an estimated average of 93 kg of other commercial species were incidentally-caught and then landed per tonne of directed catch (Table 3).

Estimated incidental capture and discarding of other taxa during the cod gillnet fishery was also relatively higher during the early 1990s compared to later years (Fig. 2c,d). Up to 200 tonnes annually of large decapods (mainly *Hyas* sp. crabs and some snow crab, *Chionoecetes opilio*) were estimated to have been discarded in the early period. Important amounts of skates and wolffishes were also estimated to have been discarded. However, one must bear in mind that estimates prior to 1996 are based on few observed trips and therefore subject to considerable imprecision.

Over the entire series, the average estimated discard rate in the cod gillnet fishery was 33 kg of fish biomass per tonne of directed catch (Table 3). Other than the taxa already mentioned, discards also included sculpins and sharks. An estimated average 16 kg of invertebrates (mainly crabs) per tonne of directed catch were discarded.

Greenland halibut (gillnets)

Observer coverage in this fishery has varied around 5% of trips, with a rising trend since the early 1990s (Fig. 3a). An estimated annual average of about 40 kg of other commercial groundfish were caught and landed per tonne of Greenland halibut captured (Table 3; Fig. 3b). The species in question are mainly American plaice and redfish (*Sebastes* sp.), but also Atlantic halibut and spiny dogfish. Most of the other species captured were discarded, at an estimated rate of about 95 kg of fish (mainly black dogfish, *Centroscyllium fabricii*, and skates) and 65 kg of invertebrates (mainly snow crab and northern stone crab, *Lithodes maja*) per tonne of Greenland halibut captured (Table 3; Fig. 3c,d).

American plaice (gillnets)

American plaice are mainly captured in mobile gear fisheries in the southern Gulf. Directed catches in fixed gear are a small proportion of total landings and have declined to (near) zero in the early 2000s (Fig. 4a). When there were landings from the American place gillnet fishery, observer coverage levels varied between 0 and 4% of trips. On average, other commercial species (mainly Atlantic cod) comprised a higher proportion of the catch in observed trips than the directed species (Table 3; Fig. 4b), suggesting possible improper attributions of 'target'

species in our analysis. Most of the other species captured were discarded, at an estimated rate of about 192 kg of fish (mainly skates and sculpins) and 1010 kg of invertebrates (mainly snow crab and *Hyas* sp.) per tonne of American plaice captured (Table 3; Fig. 4c,d).

Winter flounder (gillnets)

The winter flounder gillnet fishery, termed a 'tangle-net' fishery, takes place on herring spawning beds, where winter flounder aggregate to feed on the freshly laid eggs. Directed landings have generally declined since the early 1990s (Fig. 5a). Observer coverage levels were low, varying generally around 1-4% of trips. Cod and white hake are the main incidentally captured commercial species in this fishery. A very low proportion of observed directed catches in 1994 likely contributed to the very high estimate (>8000 tonnes) of discarded commercial fishes (Fig. 5b). Excluding that year an estimated annual average of about 223 kg of other commercial groundfish are caught and landed per tonne of winter flounder captured (Table 3). On average, about half of the other incidentally captured taxa were discarded (Table 3; Fig. 5c,d). Retained taxa included sculpins and other small demersal fish, whereas discarded taxa included mainly rock crabs (*Cancer irroratus*), skates, sculpins and other small demersals. The estimated discard rates are 29 kg of fish and 37 kg of invertebrates (mainly rock crabs) per tonne of directed catch.

Cod (longlines)

With the exception of moratorium years in which only the Sentinel surveys were opened for cod (1995-1997; 2003) observers covered about 20% of trips in the cod longline fishery (Fig. 6a). Compared to the cod gillnet fishery, non-target commercial groundfish comprised a higher proportion of the catch; estimated at about 200 kg landed per tonne of directed catch (Table 3; Fig 6b). Atlantic halibut, white hake and spiny dogfish were the main incidentally-caught commercial species. An estimated average of about 30 tonnes of non-commercial species were incidentally captured annually, about half of which was retained and landed (mainly Greenland cod, *Gadus ogac*, and some sculpins) (Fig. 6c,d). Skates, sculpins and eelpouts were the most frequently discarded taxa observed. The change in the relative proportion of these species in the discarded catch over time (Fig. 3d) reflects relative changes in the abundance in the ecosystem (Benoît and Swain 2008).

Atlantic halibut (longlines)

Targeted landings of halibut in the longline fishery have increased almost continually since 1991 (Fig. 7a). Coverage levels prior to 2003 were generally about 5% of trips. Increases in target coverage levels in 2001 and 2002 (see Benoît and Allard 2009) resulted in an increase of realized coverage to about 10% of trips for 2003 onwards. Incidental capture of other commercial groundfish (e.g., cod, white hake, Greenland halibut and spiny dogfish) in this fishery can be high, with estimates averaging 566 kg landed per tonne of halibut (Table 3; Fig. 7b). Other species commonly captured in this fishery include Greenland cod and wolffishes, which were generally retained by harvesters (Fig. 7c), and skates, sculpins and eelpouts, which were commonly discarded (Fig. 7d). The average estimated annual discard rate in this fishery is about 150 kg per tonne of halibut (Table 3).

Cod (handlines)

Observers have only been deployed to the cod handline fishery since 1999, after which coverage levels varied between about 2-8% of trips (Fig. 8a). The estimated rates of incidental catch and discarding in this fishery are by far the lowest of the fisheries considered here (Table 3; Fig. 8b,c,d). Observed incidentally captured taxa included small pelagic fishes, sharks and sculpins.

Catch and discard rates in NAFO 4T mobile-gear fisheries

There have generally been two principal groundfish mobile-gear fisheries in the area, one targeting mainly cod and the other flatfish (American plaice and witch flounder, *Glyptocephalus cynoglossus*). The gears used are mainly bottom trawls, and Danish and Scottish seines. We estimated catch and discard rates for these fisheries to provide a comparison to rates in fixed-gear fisheries.

The cod mobile-gear fishery targets aggregated migrating cod and as a result the estimated incidental capture rate of other taxa is generally lower than most of the other fisheries considered here (except the handline fishery) (Table 3). An estimated average about 15 kg of fish and 12 kg of invertebrates were discarded per tonne of cod captured. Incidental capture and discard of other taxa is considerably higher in the flatfish fishery, more in line with most of the fixed-gear fisheries considered (Table 3).

POTENTIAL POST-RELEASE SURVIVAL

The vitality of captured fishes as reported by observers differed among species, and for cod, among fisheries (Table 4). Species such as Atlantic halibut, wolffish and spiny dogfish appeared generally to be in better condition and to suffer fewer injuries, compared to gadoids such as Atlantic and Greenland cod, haddock and white hake. Skates are particularly susceptible to tearing of the mouth in the longline fishery.

Cod captured in gillnets were in worse shape than those captured on hooks (Table 4), presumably as a result of suffocation and abrasion. Survival in gillnet-caught fish depends a lot on soak time (e.g., Bettoli and Scholten 2006), and relatively short soak times in the fishery in 2005-2006 (generally 24 hrs.) likely explain the high proportion of fish that were nonetheless alive when sampled. Cod captured using handlines were in the best condition, though a moderate incidence of hook-related injuries were noted.

Vitality scores related well to short-term survival in all species studied (Table 4). For all species, some unresponsive individuals scored as moribund (vitality code 4) nonetheless survived at least 48 hrs. Short-term survival for trawl-caught winter flounder, skates and sculpins was relatively high for vitality codes 1 and 2. Survival was considerably lower for cod. Assuming that the vitality code-specific short-term survival assessed using trawl-caught fish also applies to fish caught in fixed gear, the combined results of the observer and experimental studies suggest that overall survival-potential of discarded cod (and likely other gadoids) would be low in the gillnet fishery and low to moderate in the hook fisheries. The overall survival-potential of discarded winter flounder and sculpins in longline fisheries appears relatively good, while the potential for skates would depend on their ability to resume feeding despite their injuries.

SUMMARY

To assess the direct impact of fisheries on biodiversity one needs to consider, among other things, the demographic and life-history susceptibility of species to overexploitation, the intensity of incidental capture (e.g., bycatch rates), the total target species fishing effort or catch (to derive estimates of total incidental catch) and the potential survival of discarded individuals (e.g., Jennings et al. 1997, 1999; Levin et al. 2006; Benoît and Swain 2008; Swain et al. 2009). In this working paper, we have presented estimates of total incidental captures and rates in a variety of NAFO 4T fixed gear groundfish fisheries and preliminary analyses of potential survival of discarded fish.

Rates of incidental catch and discarding vary among NAFO 4T fixed gear fisheries. The rates, as well as estimated total amounts, were by far the lowest in the cod handline fishery. Based on observations for cod, fish captured in this fishery are also generally in good shape and therefore survival of any discarded fish is expected to be good, particularly for more resilient taxa such as sculpins. At the other end of the scale of fisheries considered here, rates of incidental catch and discarding were highest in the American plaice gillnet and Atlantic halibut longline fisheries. Total amounts of incidental and discarded catch were comparatively low in these fisheries. It is important to note that the catches of the target species have also generally been low, a situation that is changing for the Atlantic halibut fishery. Total discards were consistently the highest among years in the Greenland halibut gillnet fishery (median 137 tonnes of fish and 94 tonnes of crabs per year; Fig. 3d). Post-release survival of the most frequently discarded taxa in this fishery (skates, black dogfish and crabs) has not been assessed.

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Table 1. Description of the codes used to qualify the vitality of captured fishes during commercial and Sentinel survey fishing trips.

Vitality	Code	Description
Excellent	1	Vigorous body movement; no or minor external injuries only
Good / Fair	2	Weak body movement; responds to touching/prodding; minor external injuries
Poor	3	No body movement but fish can move operculum; minor or major external injuries;
Moribund	4	No body or opercular movements (no response to touching or prodding)

Table 2. Description of the codes used to qualify the degree of injury of captured fishes during commercial and Sentinel survey trips.

Injury	Code	Description
None	1	No bleeding, torn operculum or noticeable loss of scales
Minor	2	Minor bleeding or minor tear of mouthparts or operculum or moderate loss of scales (i.e. bare patch)
Major	3	Major bleeding or major tearing of the mouthparts or operculum or everted stomach or bloated swim bladder

Table 3. Median targeted landings (tonnes), and estimated catch and discard rates (kg per tonne of target species catch) in the principal groundfish fisheries in NAFO 4T, 1991-2008. Catch and discard rates were inferred from data collected by at-sea observers. Catch rates are presented for landed non-target species under quota management and for other landed species. Discard rates are presented separately for fish and invertebrates.

Gear	Target species	Median targeted landings	Landed		Discarded	
			Non-target commerical groundfish	Other species	Fish	Invert.
Gillnets						
	Atlantic cod	438.4	93.1	4.1	32.6	16.0
	Greenland halibut	1447.1	39.1	5.1	94.7	64.9
	American plaice	37.4	1135.9	24.6	191.9	1010.0
	Winter flounder[1]	176.3	223.4	39.2	29.0	37.1
Longlines (bottom-set)						
	Atlantic cod	407.2	198.6	38.4	99.3	0.4
	Atlantic halibut	47.3	566.3	20.0	147.9	3.7
Handlines						
	Atlantic cod	194.3	0.3	10.4	5.8	0.2
Trawls and seines						
	Atlantic cod	1220.1	17.2	47.6	14.9	11.6
	Flounders	1788.2	258.0	3.0	115.4	56.4

[1] catch and discard rates were calculated excluding data from 1994, when the observer coverage level was very low.

*Table 4. Summaries of vitality and injury data collected by at-sea observers during commercial and Sentinel survey fishing trips (regular font) and of the short-term survival experiments (bold font). For each species and gear type (G – gillnets; L – longlines; H – handlines), the total number of fish sampled by observers and the percentage of fish in each vitality or injury category are presented. Survival experiment results are presented as the percentage of fish surviving at least 48 hours post capture (**%S**) as a function of the vitality code attributed to individual fish prior to putting them in the holding tanks. Some species sampled by observers were not included in the survival experiments.*

Gear /		% by vitality code					% by injury code		
%Surv.	$N_{vitality}$	*1*	*2*	*3*	*4*	N_{injury}	*1*	*2*	*3*
Atlantic cod									
G	519	32.9	33.7	21.4	11.9	224	46.0	39.7	14.3
L	3869	84.1	9.0	3.4	3.5	2367	72.9	23.3	3.8
H	450	97.1	0.2	2.7	0.0	225	51.6	43.1	5.3
%S	**646**	**65.1**	**39.4**	**14.8**	**1.9**				
Haddock									
L	42	81.0	11.9	0.0	7.1	11	81.8	18.2	0
White hake									
L	1164	75.2	13.1	7.0	4.7	731	62.2	34.6	3.1
%S	**9**	**100.0**	**66.7**	**50.0**	**-**				
Atlantic halibut									
L	962	96.4	1.5	0.8	1.4	787	86.5	12.2	1.3
%S	**5**	**100.0**	**-**	**50.0**	**-**				
American plaice									
G	20	65.0	25.0	5.0	5.0	20	100.0	0	0
L	66	84.8	6.1	3.0	6.1	45	68.9	31.1	0
%S	**874**	**88.1**	**64.8**	**53.8**	**3.9**				
Winter flounder									
L	25	80.0	8.0	8.0	4.0	0			
%S	**110**	**100.0**	**92.0**	**63.2**	**19.1**				
Wolffishes									
L	65	92.3	1.5	0.0	6.2	37	100.0	0	0
Greenland cod									
L	360	66.1	20.0	5.0	8.9	241	44.0	51.9	4.1

Table 4 (continued).

Gear / **%Surv.**	$N_{vitality}$	*% by vitality code* 1	2	3	4	N_{injury}	*% by injury code* 1	2	3
Skates									
L	181	75.7	15.5	7.2	1.7	136	21.3	67.6	11.0
%S	**149**	**100.0**	**100.0**	**62.5**	**42.1**				
Spiny dogfish									
L	31	83.9	16.1	0.0	0.0	20	75.0	25.0	0
Sculpins									
L	868	89.2	7.0	2.5	1.3	846	79.2	18.8	2.0
%S	**60**	**100.0**	**100.0**	**83.3**	**55.6**				
Wrymouth									
L	66	89.4	3.0	3.0	4.5	62	67.7	25.8	6.5
Eelpouts									
L	146	91.1	2.1	6.2	0.7	124	82.3	14.5	3.2

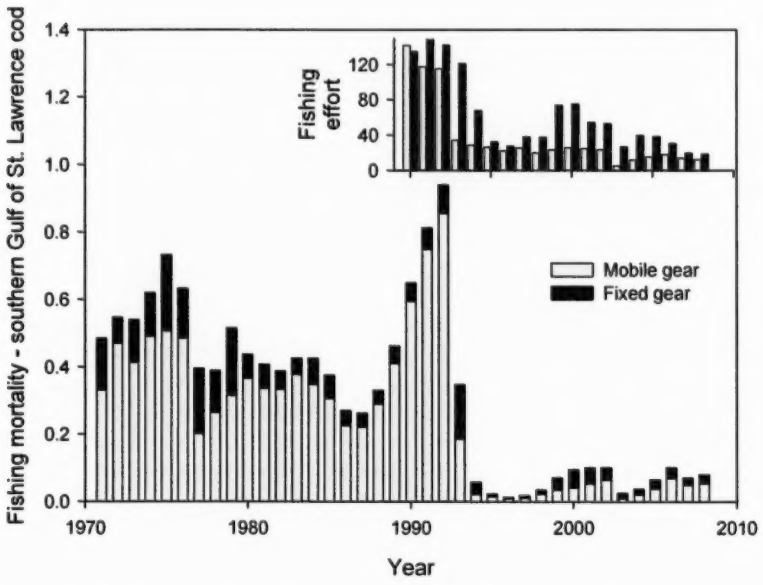

Figure 1. Main panel: Southern Gulf of St. Lawrence cod fishing mortality by gear type. Mobile gear includes otter trawls and seines (Danish and Scottish) and fixed gear principally includes groundfish gillnets and bottom-set longlines, as well as handlines (source: Swain et al. 2009). Because cod has traditionally been the principal groundfish species fished, trends in fishing mortality provide an index for fishing effort in NAFO division 4T. Inset panel: total fishing effort for mobile gear (1000s hours) and fixed gear (100s trips).

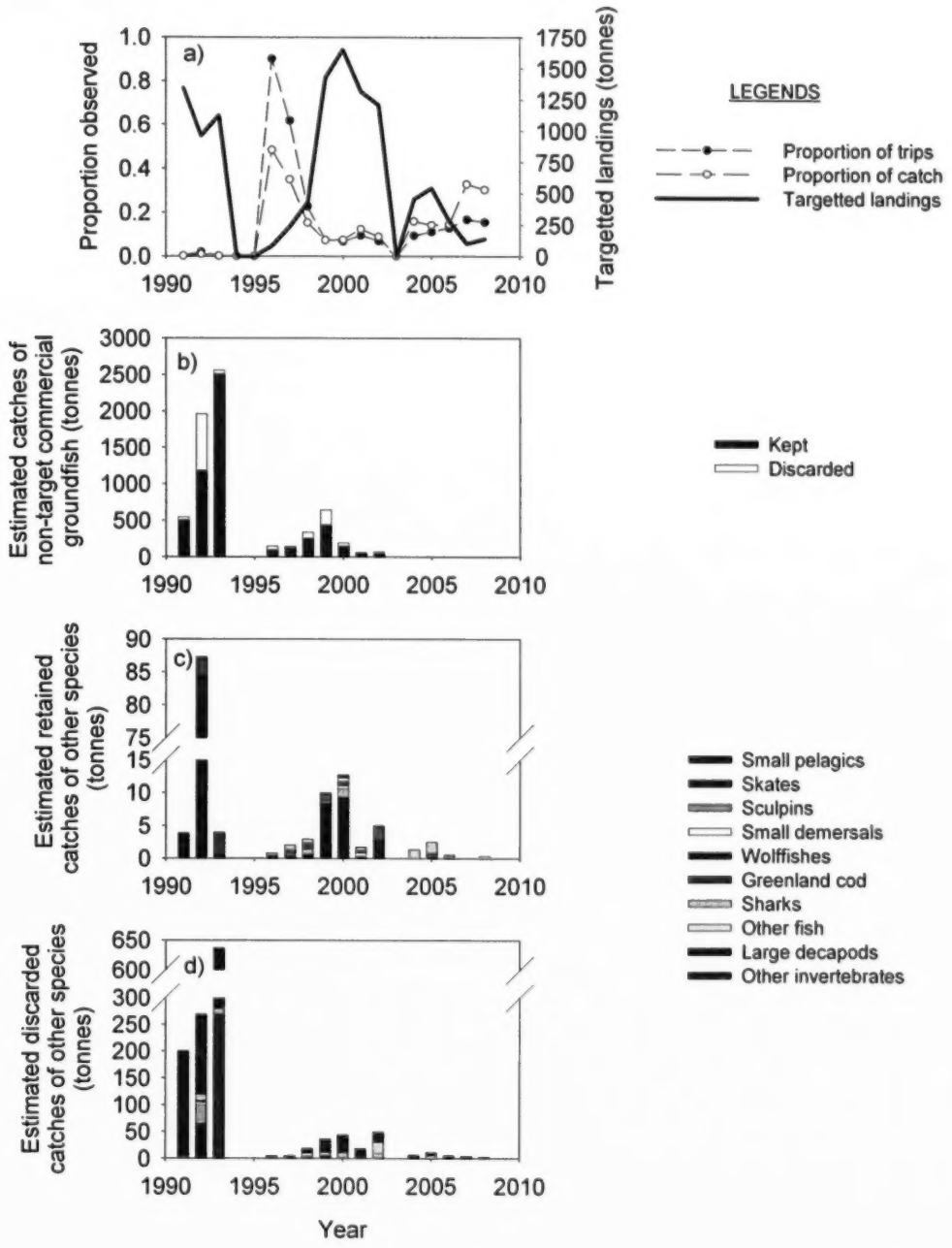

Figure 2. Cod gillnet fishery. a) Observer coverage rates as a proportion of directed trips and directed catch, and total targeted landings; b) Retained and discarded catch of non-target commercial groundfish species estimated from the observer records; c) Estimated retained catch of other fish and invertebrate taxa; d) Estimated discarded catch of these other taxa.

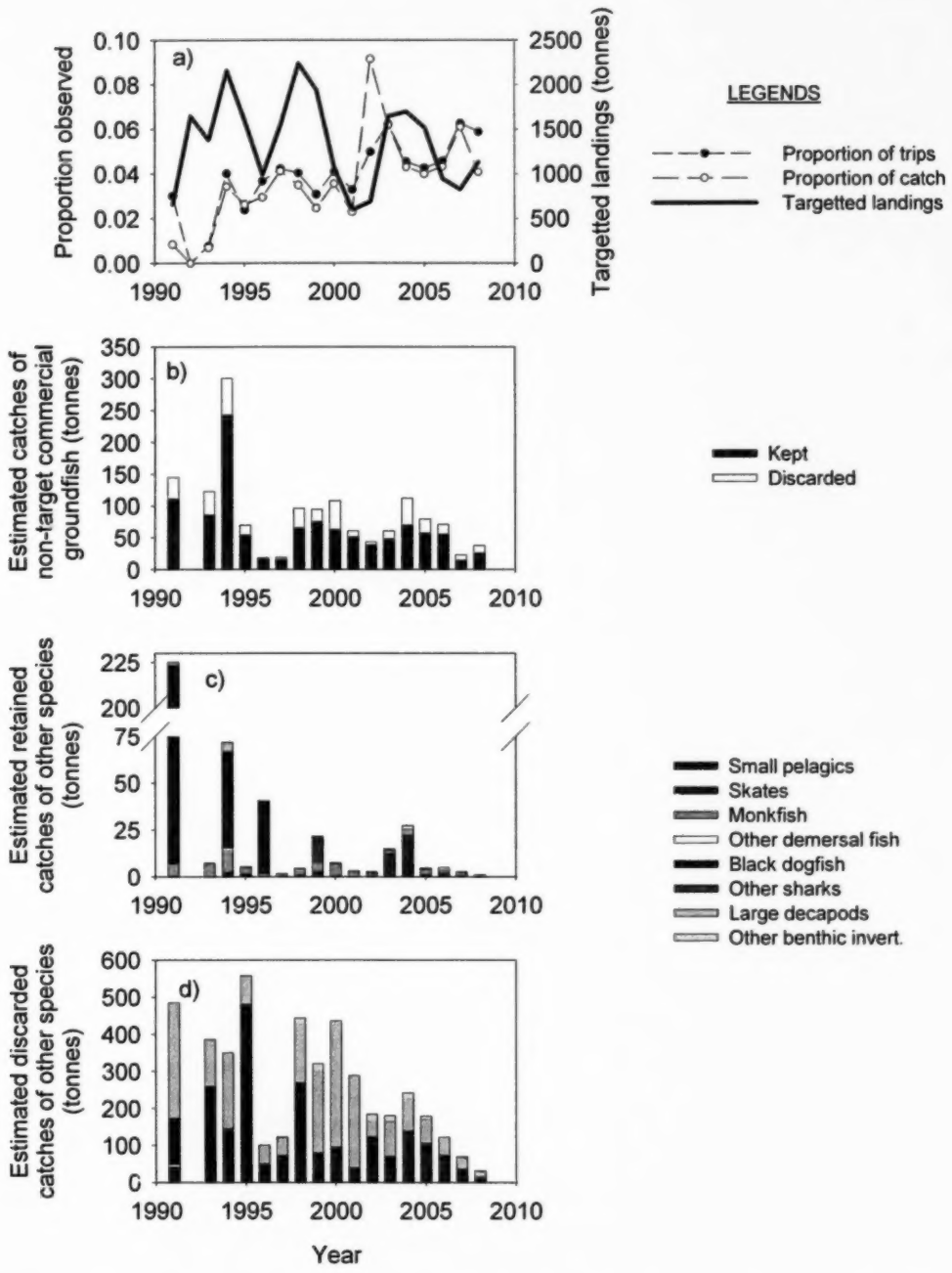

Figure 3. Greenland halibut gillnet fishery. a) Observer coverage rates as a proportion of directed trips and directed catch, and total targeted landings; b) Retained and discarded catch of non-target commercial groundfish species estimated from the observer records; c) Estimated retained catch of other fish and invertebrate taxa; d) Estimated discarded catch of these other taxa.

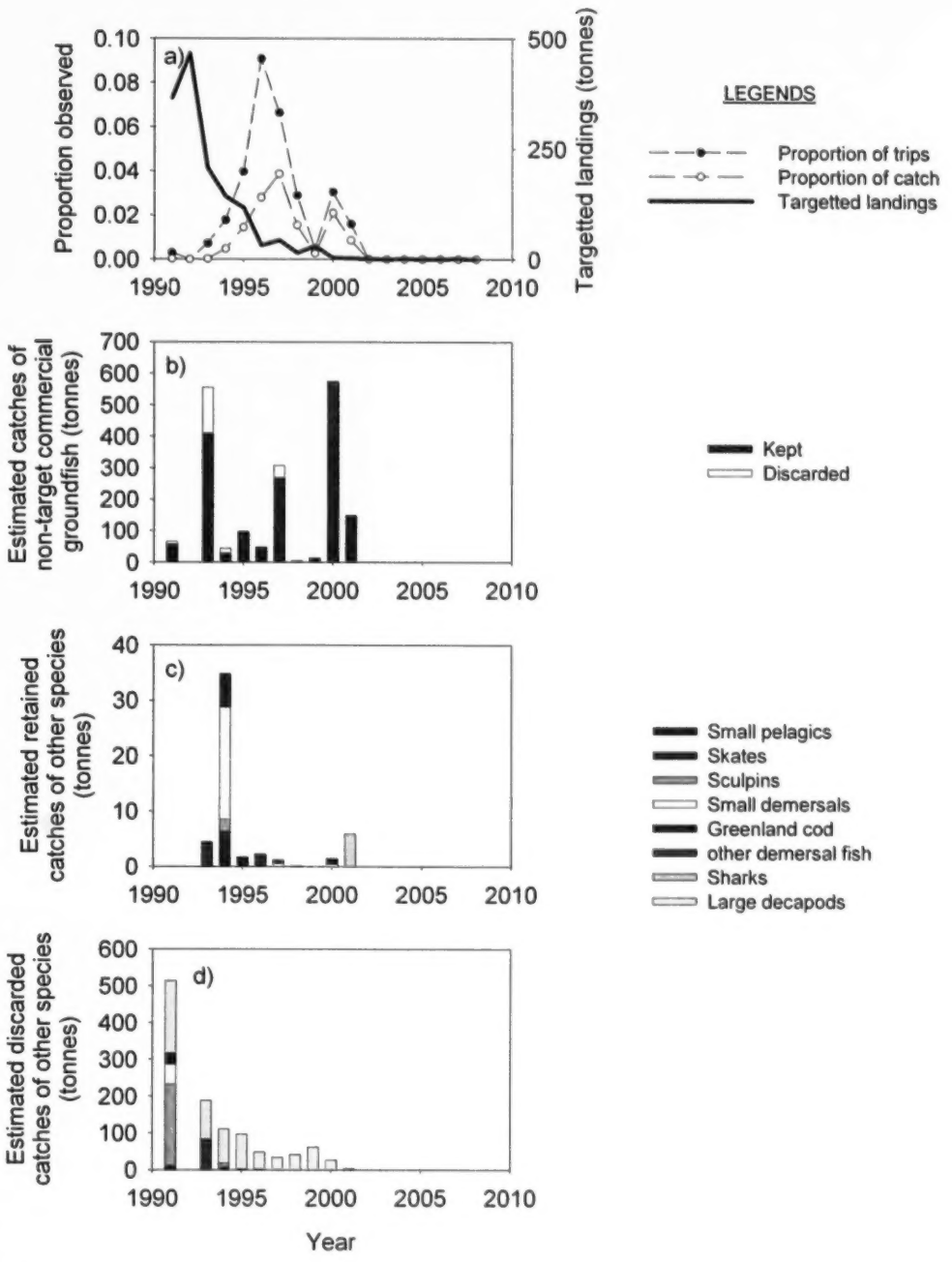

Figure 4. American plaice gillnet fishery. a) Observer coverage rates as a proportion of directed trips and directed catch, and total targeted landings; b) Retained and discarded catch of non-target commercial groundfish species estimated from the observer records; c) Estimated retained catch of other fish and invertebrate taxa; d) Estimated discarded catch of these other taxa.

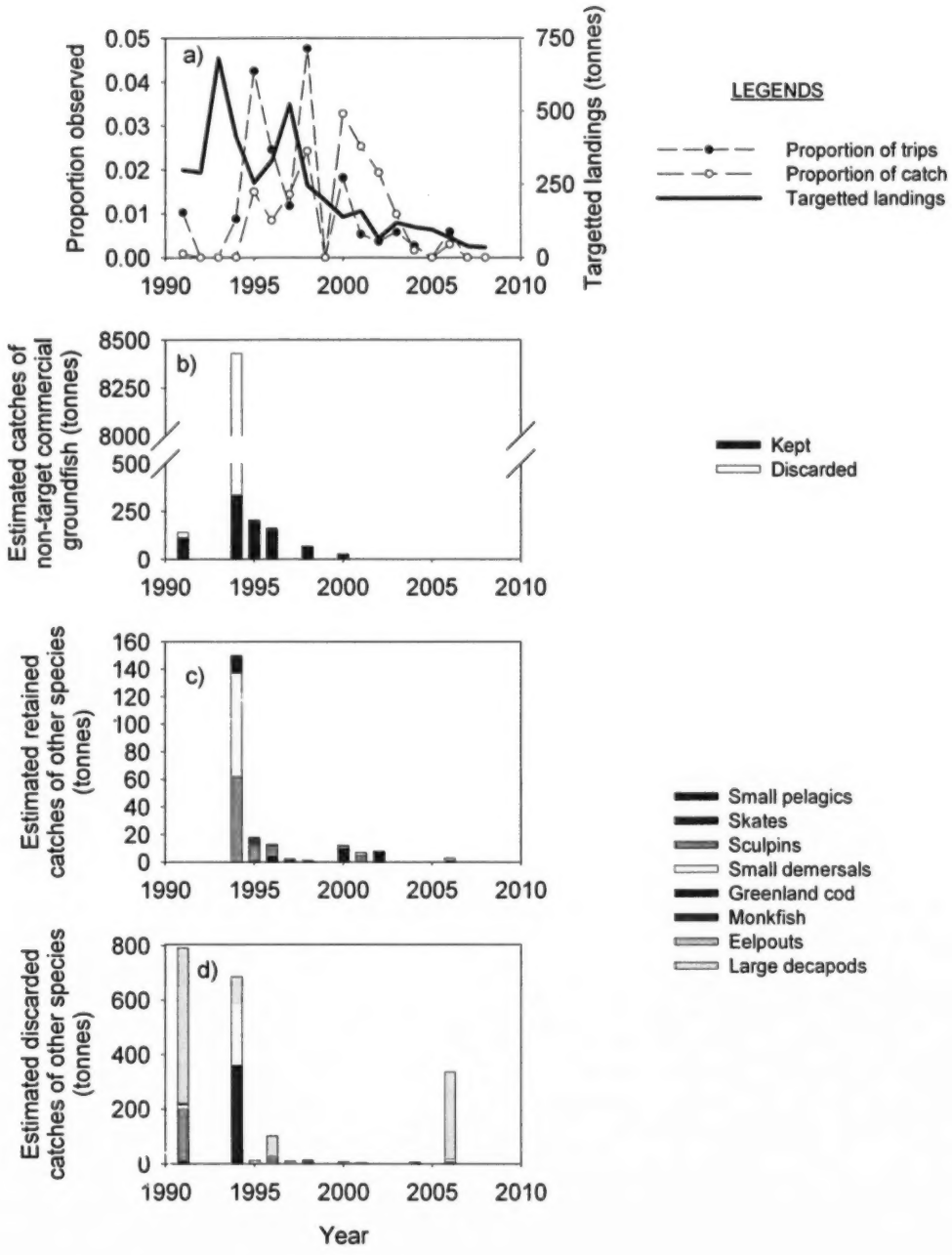

Figure 5. Winter flounder gillnet fishery. a) Observer coverage rates as a proportion of directed trips and directed catch, and total targeted landings; b) Retained and discarded catch of non-target commercial groundfish species estimated from the observer records; c) Estimated retained catch of other fish and invertebrate taxa; d) Estimated discarded catch of these other taxa.

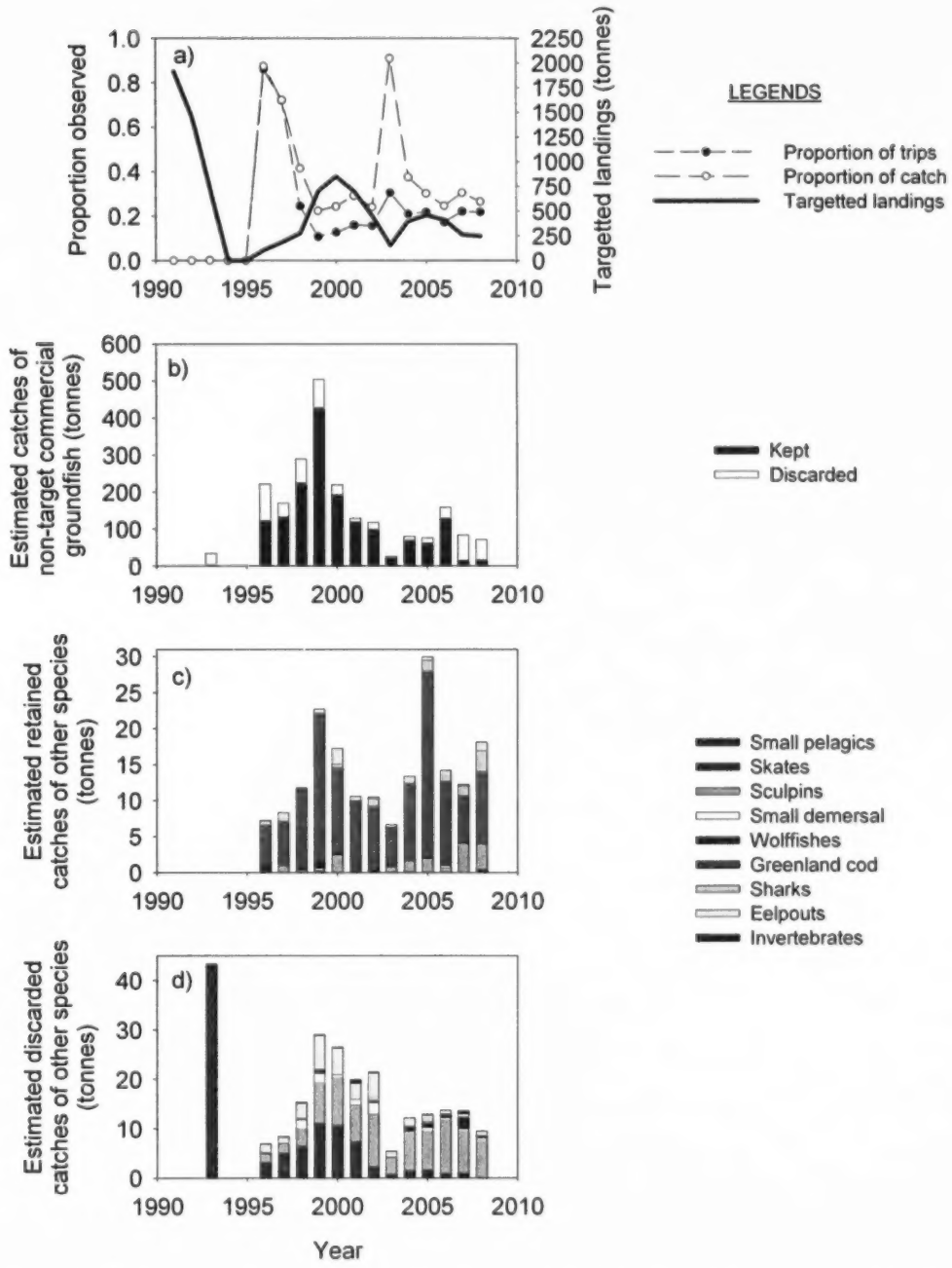

Figure 6. Cod longline fishery. a) Observer coverage rates as a proportion of directed trips and directed catch, and total targeted landings; b) Retained and discarded catch of non-target commercial groundfish species estimated from the observer records; c) Estimated retained catch of other fish and invertebrate taxa; d) Estimated discarded catch of these other taxa.

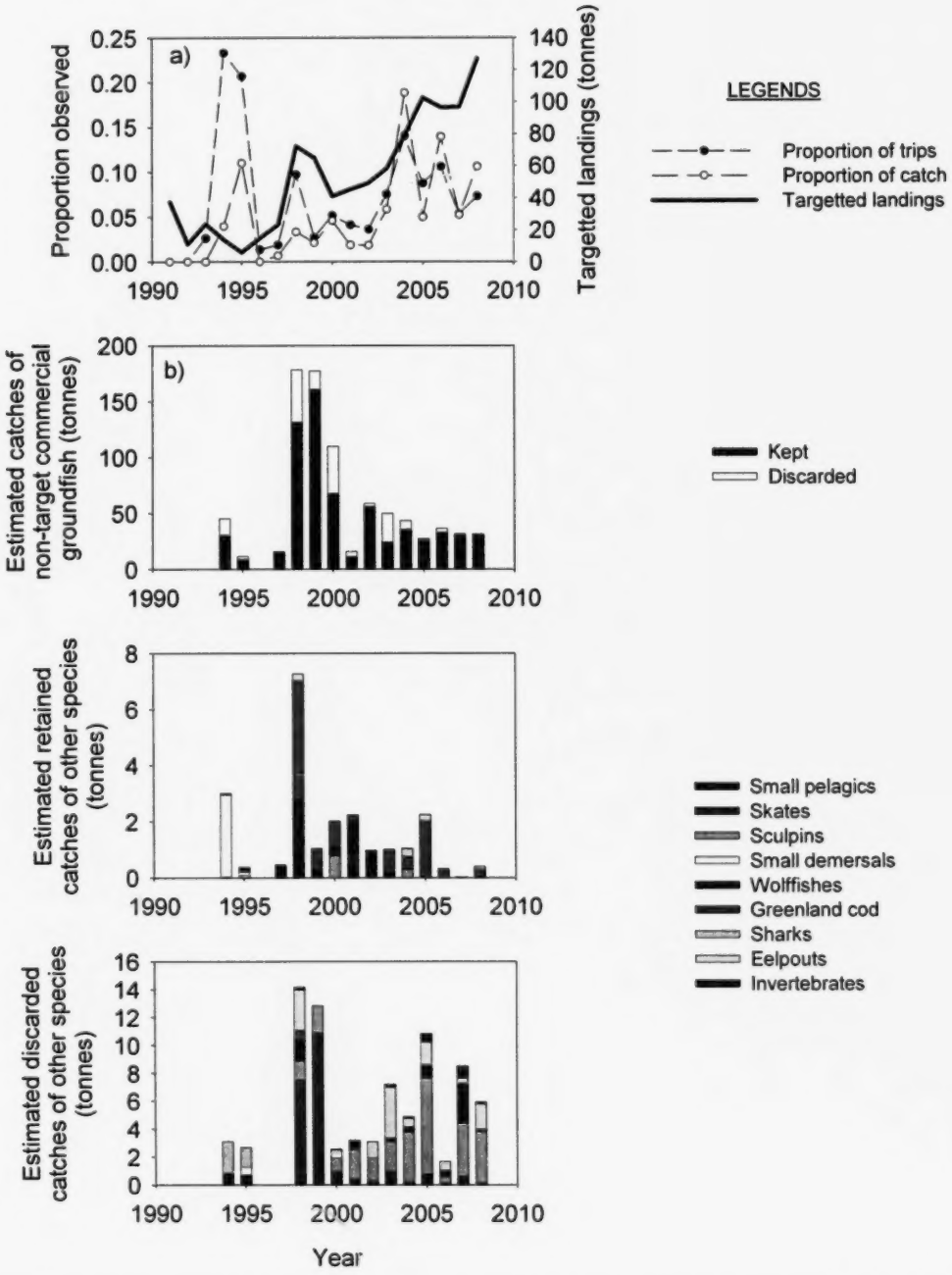

Figure 7. Atlantic halibut longline fishery. a) Observer coverage rates as a proportion of directed trips and directed catch, and total targeted landings; b) Retained and discarded catch of non-target commercial groundfish species estimated from the observer records; c) Estimated retained catch of other fish and invertebrate taxa; d) Estimated discarded catch of these other taxa.

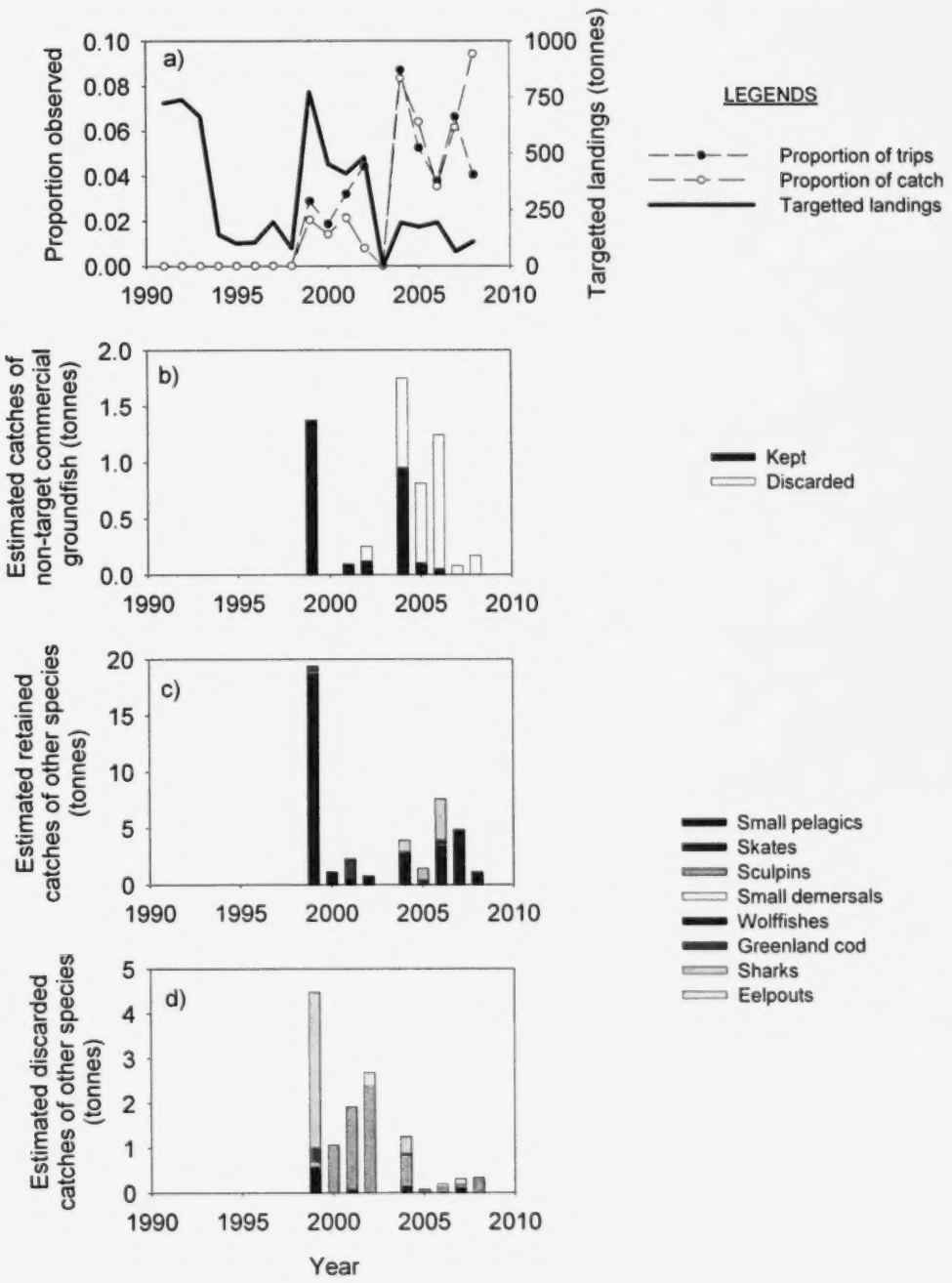

Figure 8. Atlantic cod handline fishery. a) Observer coverage rates as a proportion of directed trips and directed catch, and total targeted landings; b) Retained and discarded catch of non-target commercial groundfish species estimated from the observer records; c) Estimated retained catch of other fish and invertebrate taxa; d) Estimated discarded catch of these other taxa.